VOLUME 80 SEPARATE No. 446

PROCEEDINGS

AMERICAN SOCIETY OF CIVIL ENGINEERS

JUNE, 1954

AN ENGINEERING APPROACH TO HOT CELL DESIGN

by H. M. Glen, A.M. ASCE

Presented at
Atlantic City Convention
June 14-19, 1954

STRUCTURAL DIVISION

{Discussion open until October 1, 1954}

Headquarters of the Society
33 W. 39th St.
New York 18, N. Y.

PRICE $0.50 PER COPY

THIS PAPER

--represents an effort by the Society to deliver technical data direct from the author to the reader with the greatest possible speed. To this end, it has had none of the usual editing required in more formal publication procedures.

Readers are invited to submit discussion applying to current papers. For this paper the final date on which a discussion should reach the Manager of Technical Publications appears on the front cover.

Those who are planning papers or discussions for "Proceedings" will expedite Division and Committee action measurably by first studying "Publication Procedure for Technical Papers" (Proceedings – Separate No. 290). For free copies of this Separate—describing style, content, and format—address the Manager, Technical Publications, ASCE.

This paper was published at 1745 S. State Street, Ann Arbor, Mich., by the American Society of Civil Engineers. Editorial and General Offices are at 33 West Thirty-ninth Street, New York 18, N. Y.

AN ENGINEERING APPROACH TO HOT CELL DESIGN

H. M. Glen, A.M. ASCE[1]

1.00 Introduction

1.01 A hot cell is one so designed that its biological shielding walls will reduce the radiation intensity of its contents so that the background count outside of the cell is well within the maximum permissible dosage for its operating personnel. It is not the office of this paper to review the somewhat involved thought processes and calculations contingent with the selection of a biological shielding wall thickness. Sufficient be it to simply state that this decision is based not only on the nature and intensity of the radioactive source or sources to be handled but also on their geometry and relative positions within the cell. Normally, the Engineer will be given the required thickness of the biological shield before he begins the actual hot cell layout.

1.02 My intent is to discuss the latest design practices involved in not only the biological shield itself but also in its necessary auxiliaries such as viewing windows, material and personnel access doors, manipulators and service requirements. To accomplish this as simply as possible, I chose a small, all-purpose cell which contains practically all of the features usually found in larger and more complex cells.

1.03 Cells handling radioactive isotopes, fission products, etc., are concerned primarily with the shielding of gamma radiation. For, unless accelerated by Cyclotrons, Betatrons, etc., alpha and beta particles are normally not considered in the design of hot cells. This is because shield thicknesses sufficient for gamma radiation will be more than ample for these two radioactive particles. In general, neutrons are not considered a factor in the design of hot cells, either. This is fortunate since the shielding of neutrons is not only difficult but its design data is in general of a classified nature.

An All-Purpose Hot Cell Using Argonne-Type Slave Manipulators

2.00 General Description

2.01 Fig. 1 shows the general exterior arrangement of the small, all-purpose hot cell. Since this particular cell was installed within an existing building facility, it necessitated certain modifications to the building which will not be covered in this paper.

2.02 On Fig. 10, the proposed operating procedure of this hot cell is clearly indicated. In general, it is as follows: the source, in a lead shipping container or pig, is introduced into the cell through the personnel door by the use of a small, fork lift-type truck. Once this lead personnel door is closed and latched, the container is opened by using the slave arm of the manipulator. The source is then removed from the shipping container and placed on the working level of the hot cell by this manipulator. From this resting place,

1. Supervisory Structural Design Engineer, Oak Ridge National Laboratory, Oak Ridge, Tennessee

it may be clearly observed through the zinc bromide liquid window. This source is then introduced into any one of a number of pieces of chemical or physical apparatus and the experiment or operation under consideration performed. In Fig. 5, we see the shipping container being introduced into the cell.

2.03 In general, the components of the cell under consideration are as follows:

a. The biological shielding walls are of poured barytes concrete.
b. The interior of the cell is roughly 5'-0'' wide by 3'-3'' deep by 4'-3'' high. The floor and lower portion of its walls are lined with stainless steel. Above this, the walls and ceiling are covered with white Amercoat 33.
c. The liquid viewing window is filled with zinc bromide solution.
d. The material and personnel doors are steel encased lead.
e. The manipulators used to service this cell are two Argonne, Model 4, master slave type.
f. Gas, air, water, vacuum, hot off-gas, hot and process drains, cell ventilation, electric power and lighting are provided.

3.00 Detailed Description of the Above Cell Components

3.10 The biological shield

3.11 On Fig. 9, we note that the side and front wall thicknesses of this cell are 2'-0'' of poured barytes concrete. This is the equivalent of seven and one-half inches of lead, or thirty-eight inches of regular poured concrete. The back wall thickness was reduced to twelve inches of poured barytes concrete. This was possible because it had been decided that this, the west face of the cell, was to be out of bounds for operating personnel, except when the radioactive source had been enclosed within its lead shipping container, or pig, for servicing by the fork lift-type truck.

3.12 The following mix was used in pouring the barytes shielding walls. Four hundred and twenty-four pounds of coarse barytes aggregate, three hundred and twenty-one pounds of fine barytes aggregate and a ninety-four pound sack of portland cement. Water was held to a minimum consistent with the desired density and three-thousand pound compressive strength at twenty-eight days.

3.13 The front corners of the cell walls were beveled at forty-five degrees to provide a flat surface for periscope inserts, as well as to save concrete.

3.14 Scatter shielding for gamma radiations through the roof of this cell was provided by laying a 2-inch thick layer of lead brick on the steel cover plates that were slotted to provide manipulator access. See Fig. 8.

3.15 Comments on biological shields

3.15a The primary function of a biological shield is to reduce the initial radiation intensity of the source, under consideration, to a safe personnel tolerance level. This normally is 7.5 mr (milliroentgen) per hour, or 50 mr (0.05r) per day.

3.15b Fig. 3 shows the relative installed costs for the more popular biological shielding materials using as unity the value for regular poured concrete. This table also indicates the comparative thicknesses of a biological shield composed of these various materials using lead as unity.

3.15c Biological shields are normally composed of materials possessing relatively high atomic weights. Of these, lead tops the list. This

substance is an excellent shielding material, especially where space is at a premium. It is widely used in the alteration or modification of existing facilities where localized shielding is desirable. Its normal usage is in the form of stacked brick. The relatively high cost of lead is the primary factor in the substitution of other materials for it whenever possible. Doors and access ports are generally composed of steel encased poured lead. And for the shielding of x-rays and very low energy gamma rays, lead is almost always used because of its superior shielding properties in this energy range.

3.15d Steel plates are now seldom used in thick shields. The exception being in the shilding walls of sampling cubicles where they are sometimes employed. In such cases, they are used in conjunction with Penberthy lead glass viewing windows which are in the same specific gravity range as steel. Steel plates are sometimes used in place of thin lead shields because of fabrication problems. These thin lead shields, because of their tendency to slump, must be held rigidly in position by a steel backing or frame. For this reason, it is generally simpler to substitute for lead a relatively thicker, self-supporting steel plate. This form of shielding is especially useful in cases where the thickness of an existing biological shield must be increased because of greater radiation hazard.

3.15e Barytes, or high density concrete, is rapidly replacing lead and steel for thick biological shields because of its relative economy as well as its superior shielding properties for very high energy gamma rays. This material is widely used in new facilities where the additional shield wall thicknesses, coincident with the use of all forms of concrete, may be incorporated into the design of the facility itself.

3.15f Barytes concrete is widely used in two forms, poured and stacked solid blocks. Poured barytes concrete is a superior material to stacked block where numerous access ports, service inserts, off-gas ducts, service piping, periscope holes, etc., are incorporated in the biological shielding walls. For it is obviously simpler to pour concrete beneath and around a maze of such openings than to lay concrete block around them. Conversely, for long, relatively thick expanses of shielding walls that are generally unbroken by access ports, inserts or other irregular openings, stacked solid block are a superior material to poured barytes concrete because of its relative economy. Stacked barytes block are often used to plug little-used, personnel access doors while the cell is activated. In large complex cells, it is often found economical to combine the use of both forms of barytes concrete, limiting the use of the poured form to those portions of the shielding wall, where the inserts and openings are grouped.

3.15g In general, the same comments as expressed in 3.15e hold good for the use of regular concrete, both poured and stacked solid blocks. Regular concrete, in both of the above forms, is widely used where excessive shielding wall thicknesses are no factor for consideration. Hot cells utilizing regular concrete in conjunction with viewing windows filled with zinc bromide solution have proven very popular in the past. This is because of the fact that both of these materials are in the same specific gravity range and because of the fact that the older type manipulators were either mounted within the cells themselves or entered the cells through the roofs which were of thinner construction than their walls. However, it decreases their workability to use the new wall-type manipulators through excessively thick shielding walls.

3.20 Interior treatment of the hot cell

3.21 On Fig. 10, we note that the floor of this particular cell is at two elevations. The lower portion, or drain pit, is designed to accommodate a lead shipping container, or pig, of the maximum foreseeable size. And the upper or working level is designed for handling the source and necessary laboratory equipment. Both floor levels are lined with 16-guage, No. 347 stainless steel, with perimeter of both floor levels being coved for ease of decontamination. The sides and front of the drain pit are also lined with the same material to an elevation equal to the lip around the upper or working level. The inside face of the personnel door is composed of stainless steel plate to complete this stainless steel usage pattern. The stainless steel liner is held in position by welded connections to the stainless floor anchors that were embedded in the poured concrete. The upper edge of this liner was either continuously welded to the stainless steel framing or lead-packed into a slot in the poured barytes concrete shielding walls.

3.22 Above this stainless steel liner, the interior of the hot cell is lined with either a thick sprayed application of Amercoat plastic paint or a stripable plastic "cocoon"-type finish. In this cell, it was decided to limit the stainless liner to that portion below the bottom edge of the zinc bromide liquid window. This decision was arrived at because the nature of the contemplated operations within this cell precluded the fact of an explosive spill occurring. However, wherever manipulators are utilized, simple spills may be expected to occur. In the case of a bad spill in which the upper portion of the cell was spattered, it was planned to decontaminate as far as possible, then, if necessary, strip off that portion of the plastic liner containing the contamination. After this had been accomplished, it would be but a simple matter to replace the cocoon liner over this spot. Some authorities go so far as to advocate the use of plastic paints or stripable cocoon on new stainless steel liners, but, in general, this is not done.

3.23 As shown in Figs. 10 and 11, the fill, placed within the hot cell to raise the existing floor level of the facility to the required working elevations, was of poured regular concrete. In a tiny cell of this nature, the use of concrete has a definite advantage over a steel frame obtaining the same result.

3.24 Comments on interior treatment of hot cells

3.24a Stainless steel is almost universally used for hot cell liners. In its application, there are two distinct schools of thought. One of these schools contends that the stainless liners should be of sufficient thickness to permit their doubling as the inner form to be used for pouring the cell walls. This school is not too particular whether the exterior surface of the hot cell be composed of mild steel plate or merely exposed concrete. The argument for the steel exterior surface is the relative ease with which all type of inserts, door frames, etc., may be welded in position between these two metal surfaces prior to the pouring of the concrete. A metal exterior surface also lends itself to the simple attachment of brackets, service piping, etc. The argument for leaving the concrete exposed is, of course, the economy of such a plan.

3.24b The second school contends that stainless steel liners should be only thick enough to stand up against repeated decontaminations. In this case, the poured concrete floors contain stainless steel floor anchors, angles, bars, or some other method for subsequently fastening the gauge stainless flooring in position. Note that stainless liners are seldom, if ever, welded to a mild steel framework or anchors. This is to prevent a mixture of the mild steel with the stainless at the point of weld with a resulting weak spot in the liner, as far as decontamination is concerned.

3.24c The effectiveness of all stainless steel liners are in direct proportion to the excellence of the welded joints involved. For the presence of a leaky weld permits seepage of the decontamination wash between the liner and the concrete with the resulting gradual build-up of contamination. Or, in an extreme case, the spill itself might occur at the faulty weld and the cell itself become unusuable until the liner around the leak is removed and the concrete chipped out and replaced.

3.30 Liquid windows or other viewing facilities

3.31 On Figs. 9 and 10, we note that in the case of the cell under consideration the operations are viewed through a two-foot by three-foot liquid window twenty-four inches thick. The metal frame of this window is of 347 stainless painted with Amercoat 31. The outside surface consists of two 1/2-inch panes of Pittsburgh high-strength safety glass. The inside surface is composed of two 1/2-inch panes of Pittsburgh non-browning glass No. 3441X. The gasket material is Koroseal No. 116. See Fig. 14 for details of this window.

3.32 Additional interior vision is obtained by two holes for periscopes located in the beveled corners of the front face of the cell. See Fig. 9.

3.33 The shielding provided by the zinc bromide window is only about seventy percent of that provided by the twenty-four inches of barytes concrete wall. This excess in shielding value is provided in the cell itself for possible future increase in the source intensity to be handled by the cell. At that time, the zinc bromide window may be replaced with Corning 843EL glass which corresponds in specific gravity with the barytes shielding wall or Penberthy lead glass may be used in conjunction with a thinner window of zinc bromide solution.

3.34 Comments on liquid windows or other viewing facilities

3.34a Viewing facilities are divided into two groups with a combination of the two types the rule rather than the exception. On the one hand, we have the liquid windows as typified by zinc bromide solution with a specific gravity in the 2.5 range. This type of window is often used with a non-browning glass interior face to deter discoloration of this face by gamma radiation.

3.34b The solid viewing facility group contains, among others, the Penberthy lead glass whose specific gravity is in the steel cast iron range, the X-ray lead glass whose specific gravity is in the 4.75 range, the Corning Glass type 843EL whose specific gravity is in the 3.25 range, and the Pittsburgh non-browning glass type 6740 or 3441 X whose specific gravities are in the 2.5 range.

3.34c The liquid-type windows may be of any thickness, but very thick ones are normally compartmented to prevent not only excessive wastage but excessive radiation exposure of personnel in the event of accidental breakage of its front face. The maximum thicknesses of single panes of Penberthy lead glass is four inches. For X-ray lead glass, the maximum is one-quarter inch. For Corning 843EL, the maximum is four inches. For Pittsburgh types 6740 and 3441X, the maximums are one inch. Composite viewing facilities consisting of several panes of glass are the rule rather than the exception. Mineral oil is often used to eliminate refraction from the various glass surfaces of a composite shield.

3.34d Zinc bromide windows are normally used in conjunction with cells having shielding walls of regular concrete. Corning 843EL is normally used with those composed of barytes concrete and Penberthy lead glass with steel or cast iron. Penberthy lead glass is used with lead shielding walls,

but, in this case, the viewing window must be somewhat thicker than the shielding wall itself. In general, it is advantageous to use a viewing facility as close as possible to the thickness of the shielding wall itself. This can usually be accomplished by the use of composite windows of different viewing materials. Lead being the sole exception, for no single nor combination of viewing materials in present usage possess the density of 11.2.

3.40 Material and personnel access ports

3.41 A lead door 4'-0" x 2'-6" x 4" thick is located in the back wall to admit shielded shipping containers containing the source, as well as personnel for periodically changing the experimental set-up. See Fig. 13 for details of this door.

3.42 Access to the cell for the introduction of reagents or special tools is through a twelve-inch by twelve-inch by eight-inch thick lead door. A tray on sliding runners is used to move these materials from the doorway to a point within the cell where they can be handled by the manipulator. See Fig. 12 for details of this door. The sliding tray is of 16-gauge, type 347 stainless steel mounted on ball-bearing, extension drawer slides, Knape and Vogt Manufacturing Company No. 1400, or equal. The tray itself is 11-7/8" x 1'-4" in size with a 1/2-inch perimeter lip.

3.43 In Figs. 9, 10, and 11, we note that the frames around these access doors are also composed of steel encased lead. This is to prevent weak spots in the biological shield wall around the perimeter of these doors. The usual procedure is to make these frames of the same thickness as the doors themselves, and of a width sufficient to present at all times shielding walls of a value equivalent to the walls in which the accesses are located. As for example: In Fig. 10, a source being removed from the lead shipping container emits gamma radiations in all directions impartially. Some of these rays will undoubtedly strike the cell wall at the point of top intersection of the inside face of the lead personnel door and the barytes concrete lintel over this door. This point would be a potential weak spot in the shielding wall had not the door frame been so designed that the gamma rays striking this spot from an emitter located as specified must pass through a thickness of lead plus barytes concrete equivalent to the twelve inches of barytes concrete wall itself.

3.44 Comments on material and personnel access ports

3.44a In certain complicated door frames, lead shot have been used, instead of poured lead, in conjunction with the steel plate encasements. This was done so that these frames could be easily fabricated, shipped, and erected empty rather than filled with poured lead. Before lead shot were specified, however, radiation tests were performed and results tabulated. It was quickly found that the shielding value of lead shot varied greatly with the size and mix used. The results of these tests were evaluated and from them it was determined to use the following size and mix: 56.2% of 7-8-inch round lead balls, 28.2% of 0.22 buck shot, and 15.6% of number 12 shot. Care had to be used in pouring these shot into the steel frames to prevent segregation. Finally, a procedure was worked out which included the pouring of the large balls in thin layers first. Buck shot were then introduced and gently tamped to facilitate their complete penetration within the layer of 7/8-inch round balls. Finally, the correct percentage of very fine number 12 shot were introduced and treated the same way. This resulted in a homogeneous mass with a minimum of segregation of its various sized components. Since the equivalent

value of this shot mass is about 80% that of poured lead, the frames must be designed larger than if poured lead were used.

3.44b In certain large cells, the personnel and equipment doors are made of the same material as the shielding walls themselves. In the case of a barytes concrete wall, the door would be constructed of solid barytes concrete blocks stacked within an open steel frame. This movable steel frame would operate on a track and could be rolled away from the cell to provide access. This type door has stepped edges to prevent radiation from beaming through the cracks around their perimeter. This type door may be employed in cells whose shielding walls are of either regular or high density concrete.

3.50 Manipulators

3.51 In Fig. 2, we see the manipulators in use. The ones shown are two Argonne type, Model 4, master slave manipulators. This type of manipulator to a large extent disregards the shielding wall thicknesses of the cells themselves. Access into the cell for these manipulators is provided by cutting two slots 12-1/2" x14-5/8" in the steel roof plates to permit movement by the vertical arms of the manipulators.

3.52 The two main types of through-the-wall manipulators are the lower case h model and the upper case H model. In both of these models, the horizontal arm penetrates the shielding wall through a stainless steel insert. In the lower case h model, the over-all height within the cell may be less than in a cell using an upper case H model. This is because the upper portion of the vertical arm has been omitted on the cell side of the lower case model.

3.53 Comments on manipulators

3.53a In general, the type of manipulator handling service required should be determined prior to the first preliminary layout of the hot cell. For the inside dimensions of the cell are closely inter-related to the type of manipulator used. An economic balance should be preserved between the initial cost of the manipulator and the cell structure needed to utilize the best features of the various types of manipulators.

3.60 Services

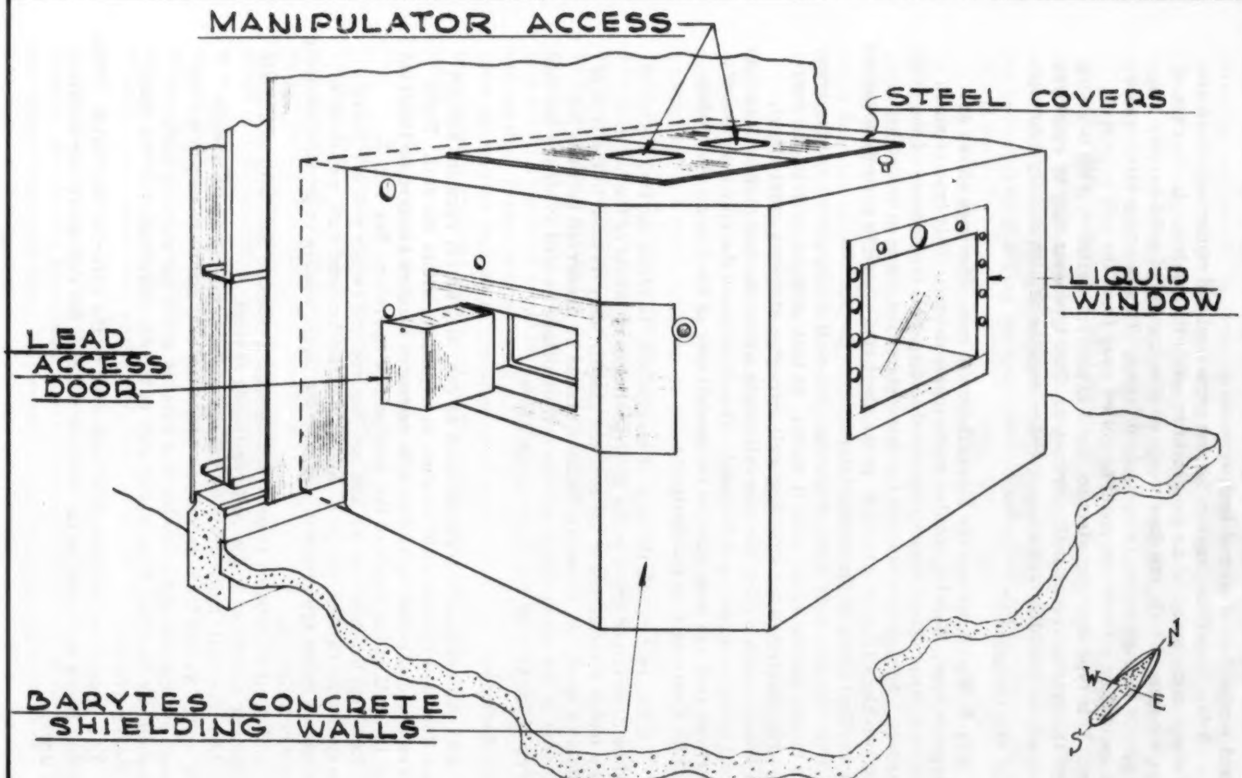
3.61 All necessary services such as gas, air, water, vacuum, and hot off-gas lines are conveniently located, in triplicate, within the cell. These services are controlled by valves with extension handles grouped on the front face of the cell within reach of the manipulator operator. See Fig. 2.

3.62 One hundred and ten and two hundred and twenty volt a/c receptacles are located within the cell. And seven two hundred watt, vapor-proof, incandescent bulbs are grouped just over the liquid window to provide adequate interior cell lighting.

3.63 Cell ventilation is provided through a transite duct with an adjustable damper connected to the cell ventilating system.

3.64 The cell floors drain by gravity to the semi-hot waste system. Highly active wastes from processes within the cell can be routed to the hot drainage system through a header that extends above the working surface. A permanently installed floor spray aids in the decontamination of the stainless steel surfaces.

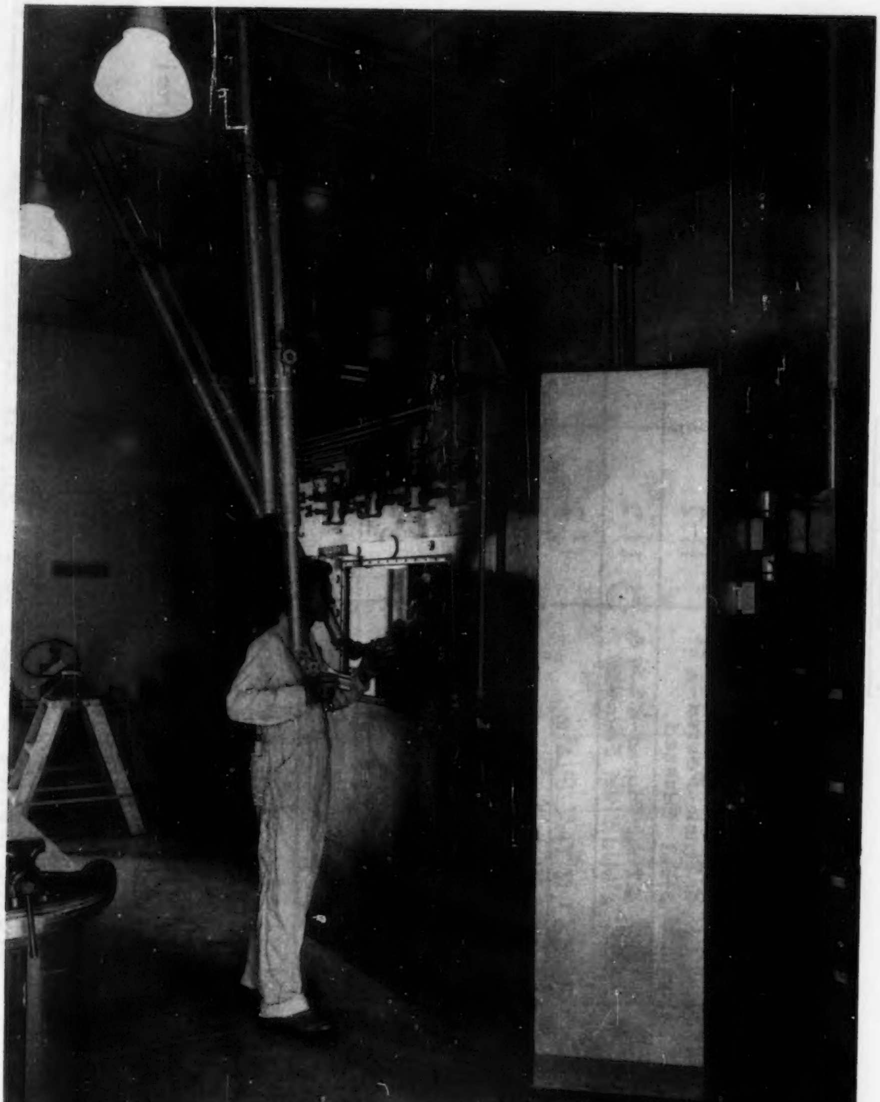
3.65 Aluminum prufcoat paint was used on the exterior cell walls. White Amercoat finish was used on the interior walls of the cell above the stainless steel liner.



PERSPECTIVE

Perspective Sketch of the Hot Cell under Consideration

FIG. 1



EXTERIOR OF CELL SHOWING MANIPULATOR USAGE Fig. 2

TABLE A

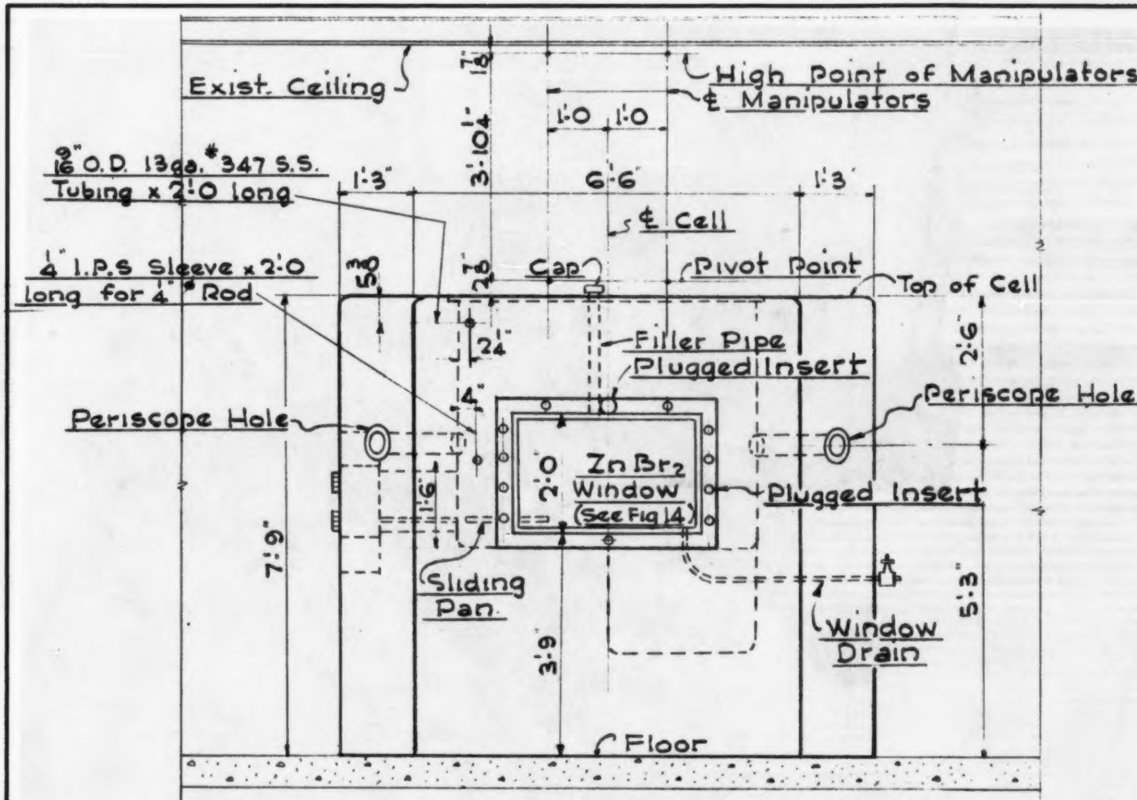
	SHIELDING MATERIAL	SPECIFIC GRAVITY	SHIELD THICKNESS	INSTALLED COST
	Lead - 4" Thick - Poured - 1/4" St. Steel Encased.	11.2	1.0	13.75
	Lead - 6" Thick - Poured - 1/4" St. Steel Encased.	11.2	1.0	11.40
*	Lead - 6" Thk. - Poured - 1/4" S.St & 1/4" Mild Steel Encased.	11.2	1.0	9.53
	Lead - 2" Thk Plate	11.2	1.0	7.86
	Lead - Stacked Brick	11.2	1.0	5.94
	Cast Iron - Stacked Brick	7.85	1.4	5.02
	Conc. Barytes - Poured	3.5	3.2	1.13
	Conc. Regular - Poured	2.3	4.9	1.00
	Conc. Barytes - Blocks	3.6	3.1	0.43
	Conc. Regular - Blocks	2.3	4.9	0.34

* Stainless Steel inside; Mild Steel outside face of Panel

1. Cost of Regular Poured Conc. Taken as Unity
2. Thickness of Lead Shield Taken as Unity
3. Relative shield Thicknesses only hold True in the gamma energy Range of 0.07 To 3.0 Million Electron Volts

FIG. 3

Table A Showing Relative Costs and Thicknesses of Shielding Materials

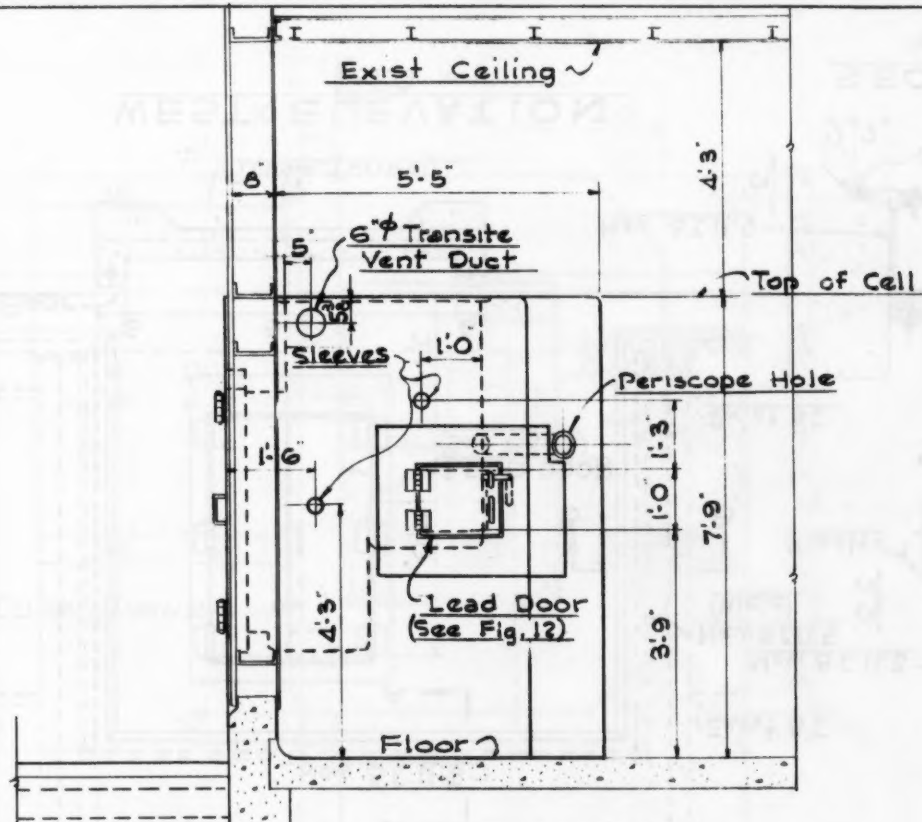


EAST ELEVATION

$\frac{1}{2}" = 1'\text{-}0$

FIG. 4

SOURCE BEING INTRODUCED INTO CELL Fig. 5



SOUTH
ELEVATION
½" = 1'-0"

FIG. 6

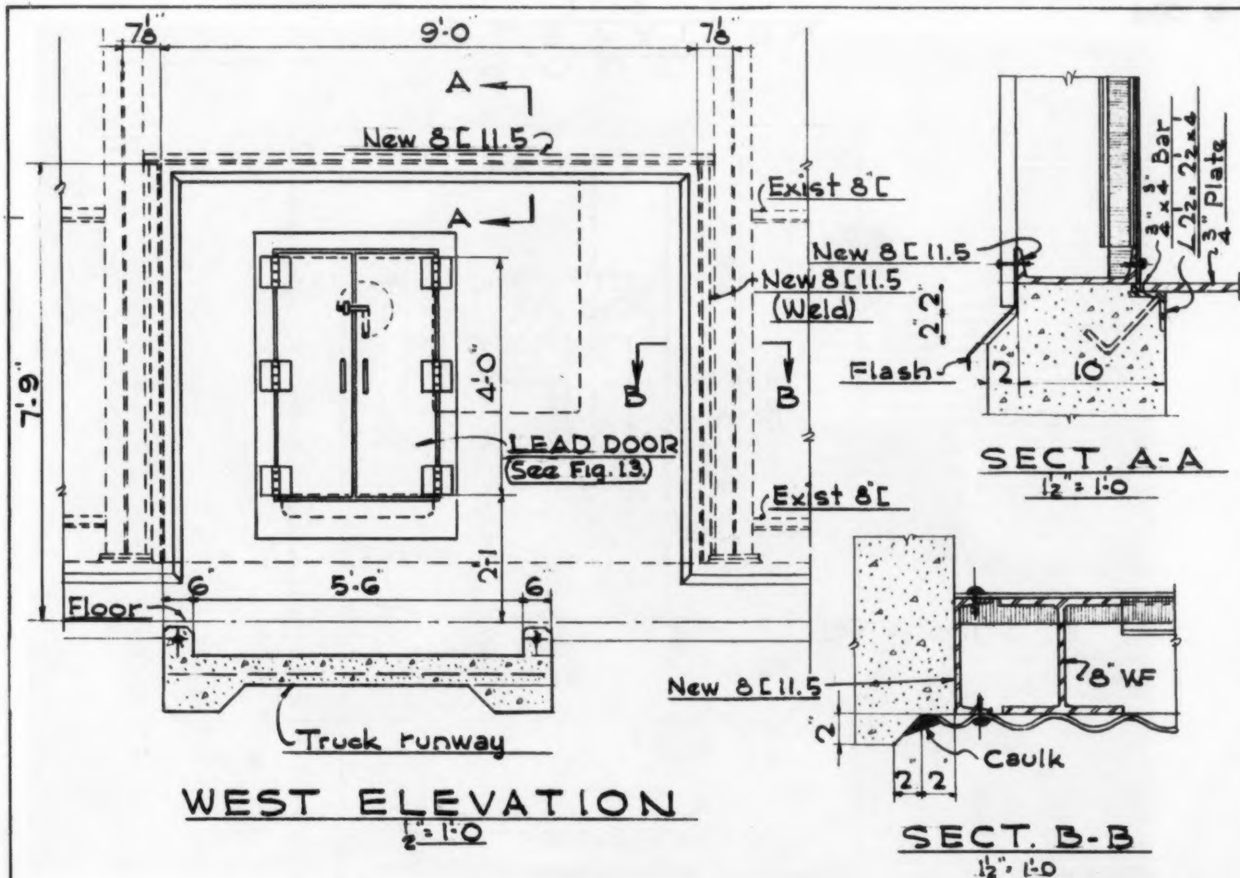
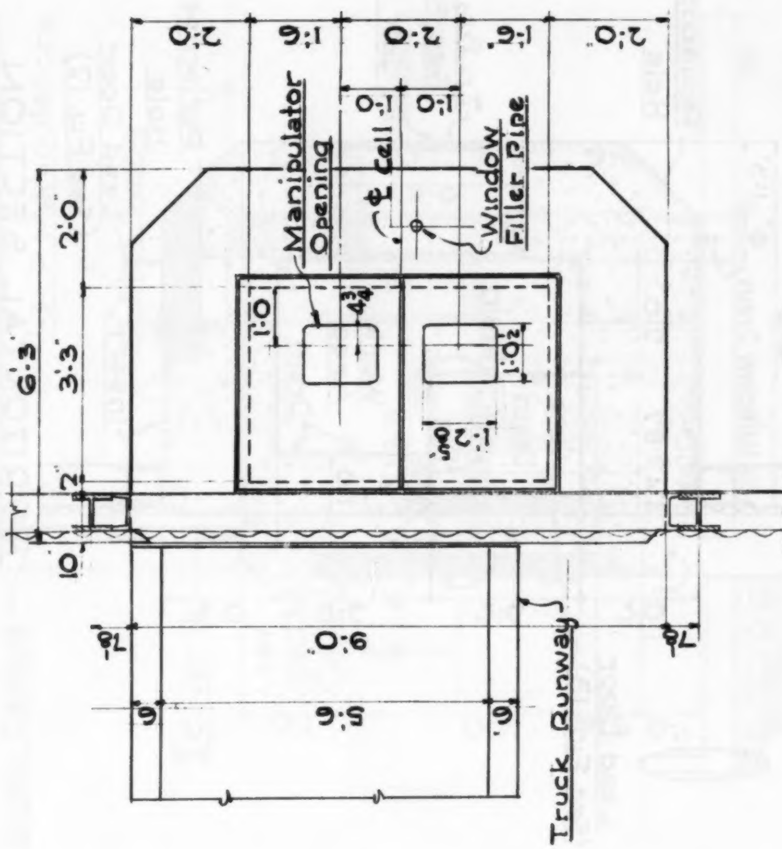
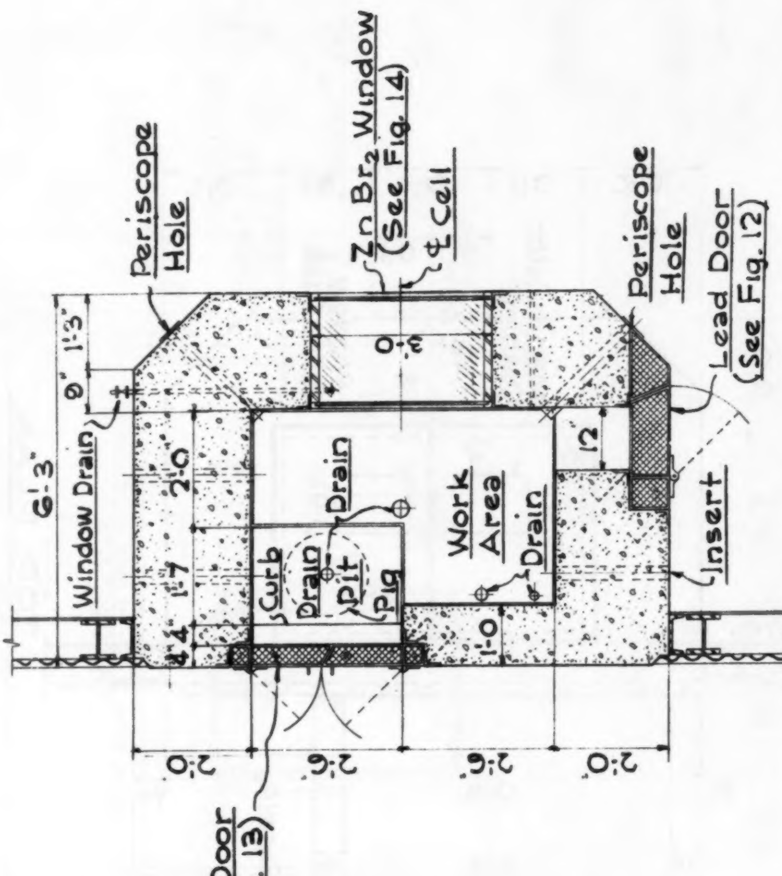

9'-0"
7 1/8"
7 1/8"
A
A
New 8 [11.5
Exist 8" [
New 8 [11.5
(Weld)
B
B
4'-0"
LEAD DOOR
(See Fig. 13.)
Exist 8" [
7'-9"
2'-1"
6"
5'-6
6"
Floor
Truck runway
WEST ELEVATION
1/2" = 1'-0
New 8 [11.5
3/4" x 4" Bar
L 2 1/2 x 2 1/2 x 1/4
3/4" Plate
2 1/2"
Flash
2
10
SECT. A-A
1 1/2" = 1'-0
8" WF
New 8 [11.5
2"
Caulk
2
2
SECT. B-B
1 1/2" = 1'-0

FIG. 7.



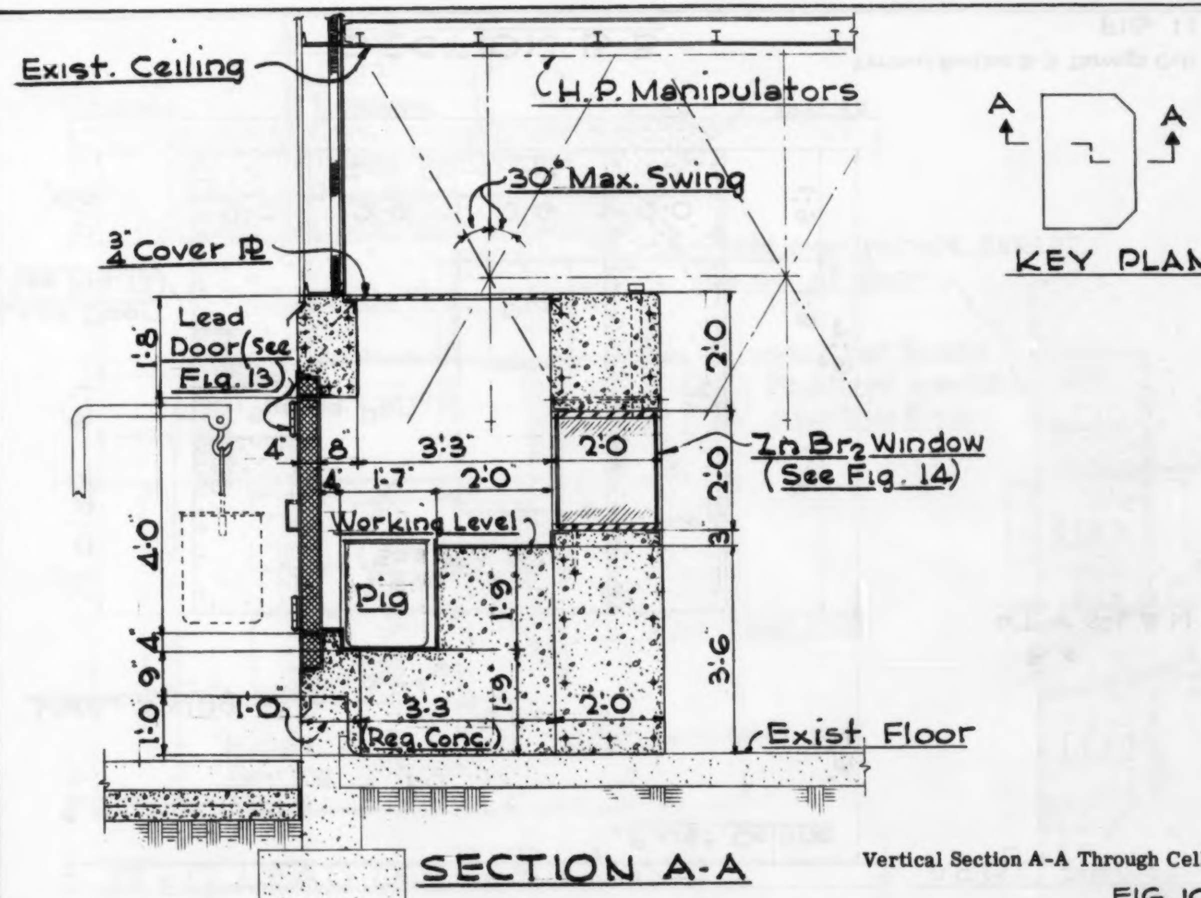
TOP PLAN

FIG. 8



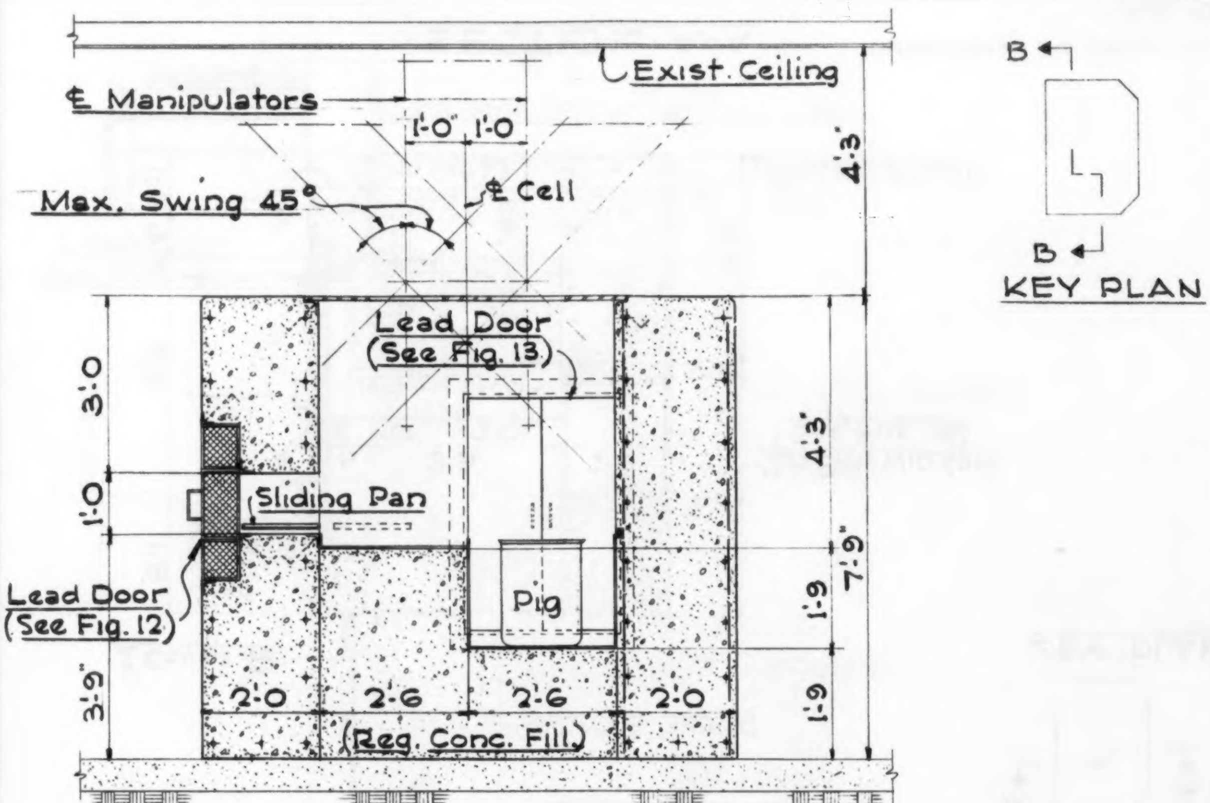
HORIZONTAL SECTION

FIG. 9



Vertical Section A-A Through Cell

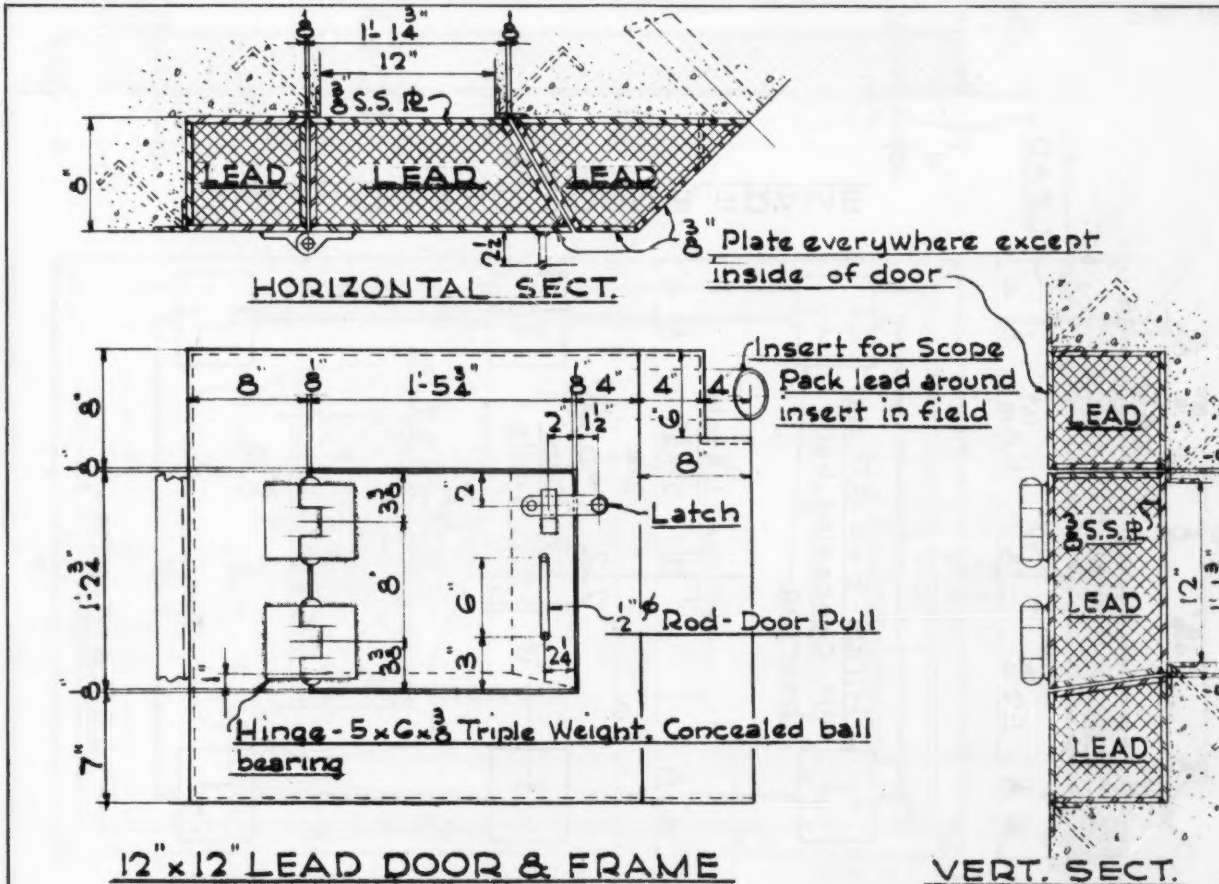
FIG. 10

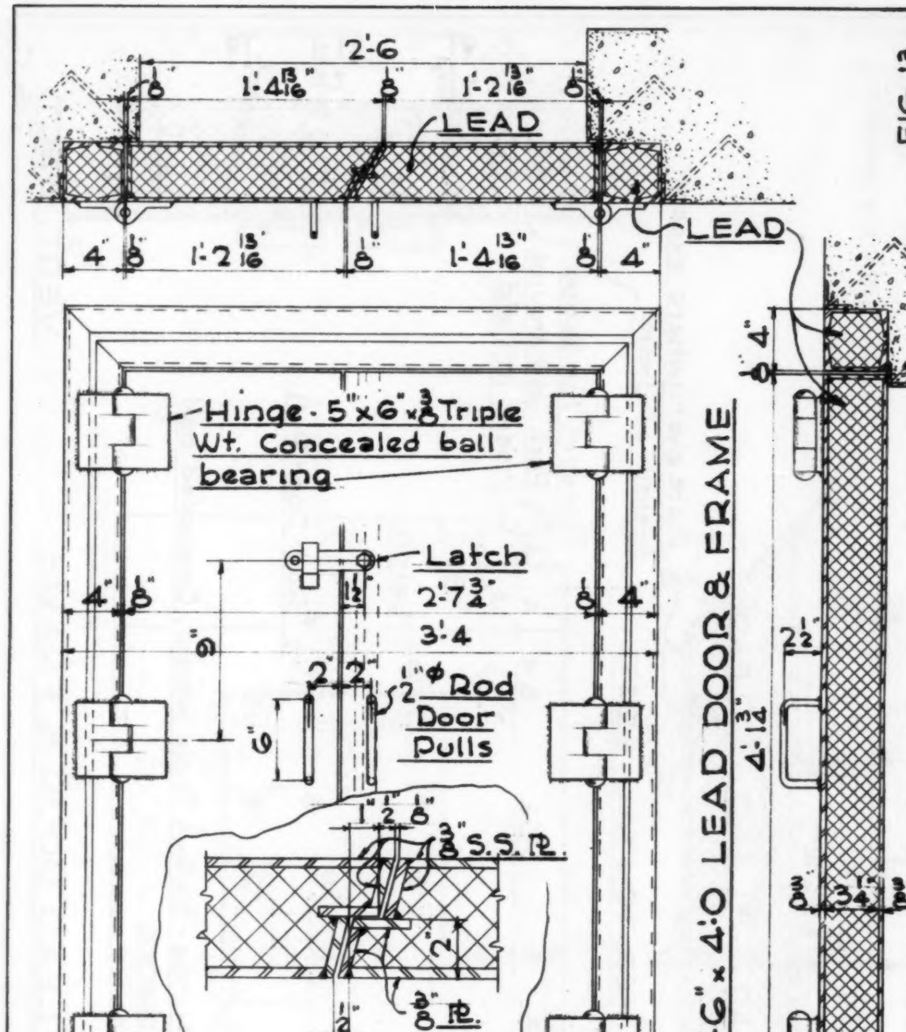


SECTION B-B

Vertical Section B-B Through Cell

FIG. 11


1'-1 3/4"
12"
3/8" S.S. PL
LEAD
LEAD
LEAD
8"
2 1/2"
3/8" Plate everywhere except inside of door
HORIZONTAL SECT.
8"
8"
1'-5 3/4"
8"
4"
4"
4
6"
2"
1 1/2"
8"
Insert for Scope
Pack lead around insert in field
Latch
2"
3 3/8"
8"
6"
3 3/8"
3"
2 1/4"
1/2" φ Rod - Door Pull
8"
8"
1'-2 3/4"
8"
7"
Hinge - 5 x 6 x 3/8 Triple Weight, Concealed ball bearing
12" x 12" LEAD DOOR & FRAME
LEAD
3/8" S.S. PL
LEAD
LEAD
8"
12"
1'-1 3/4"
8"
VERT. SECT.
FIG. 12



2'-6" x 4'-0 LEAD DOOR & FRAME

FIG. 13

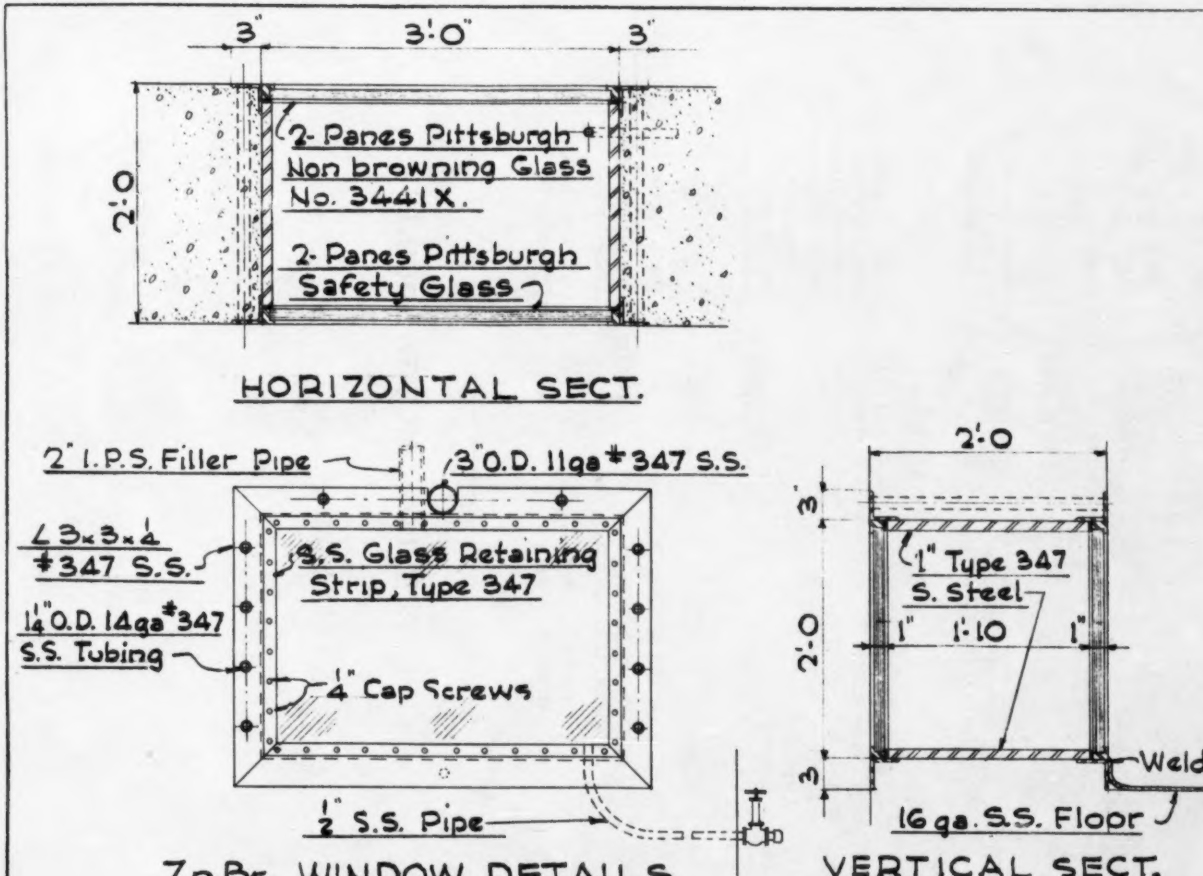

3"
3'-0"
3"
2'-0
2- Panes Pittsburgh
Non browning Glass
No. 3441X.
2- Panes Pittsburgh
Safety Glass
HORIZONTAL SECT.
2" I.P.S. Filler Pipe
3" O.D. 11ga #347 S.S.
∠ 3×3×¼
#347 S.S.
1¼" O.D. 14ga #347
S.S. Tubing
S.S. Glass Retaining
Strip, Type 347
¼" Cap Screws
½" S.S. Pipe
ZnBr₂ WINDOW DETAILS
2'-0
3"
1" Type 347
S. Steel
2'-0
1"
1'-10
1"
3"
Weld
16 ga. S.S. Floor
VERTICAL SECT.

FIG. 14